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The relationship between wood density and growth rate and the implications for the selection of Black Spruce plus trees

J. Peter Hall

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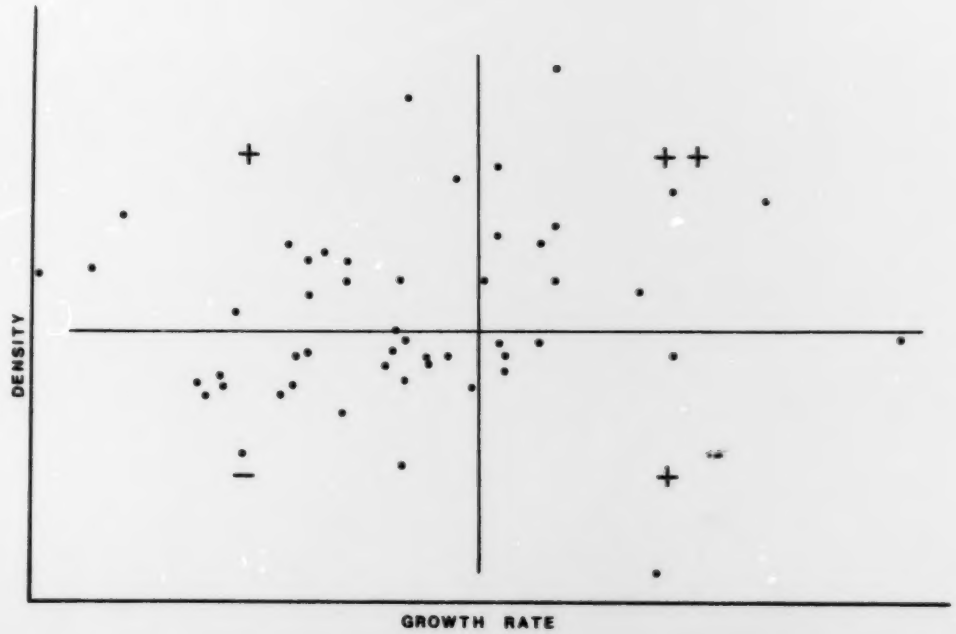

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THE RELATIONSHIP BETWEEN WOOD DENSITY AND GROWTH RATE AND THE IMPLICATIONS FOR THE SELECTION OF BLACK SPRUCE (*PICEA MARIANA* (MILL.) B.S.P.) PLUS TREES

by J. Peter Hall

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Newfoundland Forest Research Centre
Canadian Forestry Service
Box 6028, St. John's, Newfoundland
Canada A1C 5X8

Telephone No. 709-772-4817

ABSTRACT

The relationship between growth rate and wood density was examined in 12 natural stands of black spruce in Newfoundland. Growth rate and density were not closely related. No geographical trends in wood density or growth rate were observed and within-stand variation was considerably greater for growth rate than for density. A method of selection of plus trees for a tree improvement program is suggested which combines the factors of rapid growth rate and high wood density in the selected tree.

RÉSUMÉ

On a étudié le rapport entre le taux de croissance et la masse volumique du bois dans 12 peuplements naturels d'épinette noire à Terre-Neuve. Ces deux paramètres n'étaient pas étroitement reliés, et aucune tendance géographique n'a été observée. Dans un même peuplement, le taux de croissance variait beaucoup plus que la masse volumique. On propose, en vue d'un programme d'amélioration des arbres, une méthode de sélection des arbres plus qui combine le choix du taux de croissance rapide et de la masse volumique élevée.

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THE RELATIONSHIP BETWEEN WOOD DENSITY AND GROWTH RATE AND THE IMPLICATIONS FOR THE SELECTION OF BLACK SPRUCE (PICEA MARIANA (MILL.) B.S.P.) PLUS TREES

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INTRODUCTION

Black spruce is the most desirable conifer in the forest industry in Newfoundland because of its superior pulping qualities and because it is more resistant to insect and disease attack than balsam fir (Abies balsamea (L.) Mill.), the only other commercial softwood species. The black spruce component of Newfoundland forests has been reduced in recent years by two factors. Firstly, the major source of natural stands is regeneration following wildfire. Improved fire protection programs have lowered the incidence of fire. Secondly, natural regeneration following clearcutting tends to favour the establishment of balsam fir rather than black spruce stands. A reforestation program using black spruce seedlings is aimed at increasing the black spruce component of future stands. The program envisions the planting of about six million seedlings in 1984 and ten million in 1985. Within the program, it is planned to use genetically improved planting stock wherever possible. This stock will eventually be produced from seed orchards composed of selected superior (plus) trees.

Methods of selection of black spruce plus trees originally used the base-line method developed in 1977-78 for several areas of central Newfoundland (Hall and Burry 1979). Because of extensive spruce budworm damage to semi-mature and mature stands it was found necessary to modify the method. Hence, a combination of the ocular and the comparison tree methods has been used since 1980 (Morgenstern et al. 1975). To date about 100 potential plus trees have been selected based on fast rate of growth, straight stems, narrow fine-branched crowns and the absence of damage from insects and diseases. However, wood density is also a very important factor in determining wood quality for pulping purposes but is less easily identified than other phenotypic characteristics. It has been stated that wood density is the most useful single factor in wood quality determination for pulping purposes (Besley 1960). Thus, when selections are made based on rapid growth rates, trees of low density must be avoided or some of the gain in volume will be offset by a loss caused by reduced density. This situation will occur when growth rate and density are inversely correlated.

The relationship between growth rate and wood density has been studied in many conifers. Growth rate has been found to account for about one-tenth to one-third of the variation in density in western hemlock (Tsuga heterophylla (Raf.) Sarg.), amabilis fir (Abies amabilis (Dougl.) Forbes), Norway spruce (P. abies (L.) Karst) and the southern pines (Pinus spp.) (Besley 1960, Kennedy and Swann 1969). Density has

been found to be more closely related to age or position in the stem than with growth rate (Spurr and Hsiung 1954). In white spruce (Picea glauca (Moench) Voss) a slight but negative correlation was found between growth rate and density and it was thought that selections based on growth rate alone were sufficient (Chang and Kennedy 1967). No relationship between density and growth rate was found in Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) or loblolly pine (Pinus taeda L.) (Bendsten 1978, McKimmy 1966, Einspahr et al. 1969, Matziris and Zobel 1973). This would indicate that when selection is based on growth rate, there is equal liklihood of obtaining high and low density wood (Zobel 1971). It has been established that the heritability of density is moderate for white spruce and given that a small change in density has a significant economic impact on both pulp and lumber, it should be worthwhile to select for that trait (Kellogg 1982). Wood density is a complex of characters and its level of heritability is usually high enough to warrant selection based on this trait (Zobel 1961).

When selecting black spruce plus trees, attention must be given to both growth rate and density. If there is no relationship between growth rate and density in black spruce then the specific gravity of selected trees will have a normal distribution and yield should be unaffected. However, if a relationship exists, then selection based on one trait will result in the other trait being affected.

This study was established to determine the ranges of height growth and density for black spruce and the degree of relationship between the two parameters.

METHODS

Twelve stands, concentrated in central Newfoundland, and ranging in age from 10 to 95 years, were selected for study (Figure 1). In each stand 50 to 100 trees were measured. Only trees in dominant or co-dominant positions in the stand, free from insects and diseases, with straight stems and narrow crowns were measured. This is the population base from which potential plus trees would be selected. Each tree was measured for total height, diameter at 1.3 m from the base and a 12 mm diameter increment core was extracted at the 1.3 m level from the west side of the tree. The core extended from the cambium to the pith.

It has been reported that for several conifers, the mean density of the bole is well correlated with the density of an increment core from a height of 1.3 m (Hegyi 1969, Kennedy and Swann 1969, Brazier and Howell 1979). The growth rate was based on both total height (total height/age at 1.3 m) and on age at 1.3 m (age/radius or rings per cm). Wood density was calculated for each core based on the displacement method (Anon. 1950). A series of correlations of density and growth rate, age, height and diameter was calculated according to methods outlined by Steel and Torrie (1960).

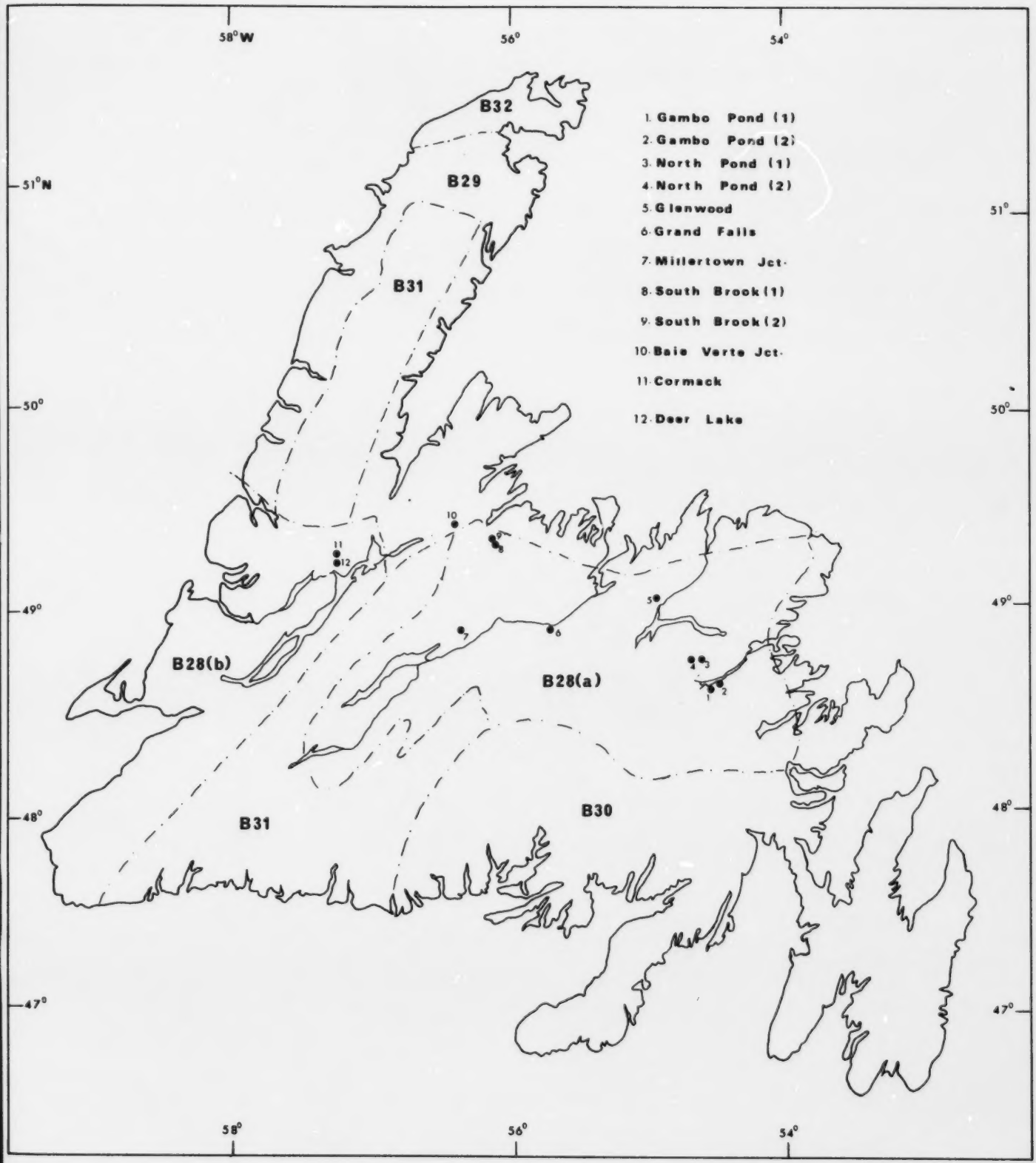


Figure 1. Newfoundland showing location of stands sampled.

RESULTS AND DISCUSSION

The stands sampled covered a wide range of age classes including the 30 to 60 year class from which plus tree selections would customarily be made (Table 1). The average stand density varied little among stands in different geographical areas but increased with age. No trends of change in density with latitude, longitude or elevation were evident.

Table 1. Stand parameters of black spruce sampled in study.

Stand	Avg. Age at 1.3 m	Avg. Tot. Ht. (m)	Diameter at 1.3 m (cm)	Growth Rate		Density g/cc
				Ht./Age	Rings/Cm	
South Brook (1)	94.3	16.1	20.9	.171	9.02	.419
Baie Verte	85.2	15.5	20.2	.182	8.44	.418
Gambo Pond (1)	71.2	14.6	17.7	.205	8.05	.422
Gambo Pond (2)	62.0	14.3	18.1	.231	6.85	.414
Millertown Jct.	58.0	13.9	18.9	.240	6.14	.412
Deer Lake	57.3	15.1	19.5	.264	5.88	.396
South Brook (2)	55.3	12.6	18.6	.228	5.95	.406
Glenwood	52.9	14.9	20.4	.282	5.19	.385
Grand Falls	43.5	13.2	17.5	.304	4.97	.395
North Pond (1)	26.1	7.6	11.4	.291	4.58	.408
Cormack	20.2	8.1	12.8	.401	3.16	.379
North Pond (2)	8.9	4.3	5.0	.483	3.56	.407

The results are consistent with those of Kennedy et al. (1968) for black spruce and also with those for a variety of American conifers (Anon. 1965). Taylor et al. (1982) also found little change in density with increasing age in white spruce. In some of the southern pines, however, it was found that density increased with decreasing latitude but not with longitude. The racial differences reported for Pinus pinaster (Nicholls et al. 1963) were not observed in the black spruce stands. Geographical variation in density appears to be quite small among Newfoundland black spruce stands. This lack of geographical trends is reflected in the grouping of central Newfoundland into one seed zone based on early height growth of selected provenances of black spruce (Khalil 1981).

The variation within stands was measured using coefficients of variation (Table 2). The data show that for characters measured, the variation was quite small. The youngest stands generally had the highest variation for age and diameter. This variation becomes less as competition begins in the stand. Tree to tree variation of height and density were both low. The between stand variation in density was only 3.4%. Although comparative data is scarce, it is apparent that the within-stand variation in black spruce was low compared to that of many of the southern conifers (Zobel 1965, 1971). The environmental limitations in the boreal spruce forest may be part of the reason for the low levels of variability; if these limitations are severe enough to prevent the expression of genetically influenced differences. Wood density is an aggregate measure of effects of percent latewood, cell wall thickness, cell size and other factors

Table 2. Coefficients of variation of stand parameters.

Stand	Coefficients of Variation in					
	Age	Height	Diameter	Ht/Age	Rings/cm	Density
South Brook (1)	4.2	7.4	11.5	7.6	11.7	6.4
Baie Verte	5.1	7.0	11.6	7.8	11.3	5.4
Gambo Pond (1)	6.4	7.8	10.8	9.3	12.4	5.2
Gambo Pond (2)	6.8	8.0	13.9	9.6	14.1	5.8
Millertown Jct.	6.1	9.9	11.8	11.4	12.3	5.8
Deer Lake	11.6	6.6	11.6	11.7	15.0	5.9
South Brook (2)	4.0	6.8	10.7	6.9	10.0	6.2
Glenwood	5.4	6.9	10.9	6.7	11.2	5.3
Grand Falls	4.6	6.6	11.8	6.4	10.4	5.6
North Pond (1)	5.4	7.7	8.9	7.7	10.2	5.3
Cormack	13.0	9.2	13.6	9.5	11.8	6.4
North Pond (2)	15.0	8.9	18.3	13.1	18.1	6.6

(Zobel 1971). The densities of sample cores estimated the net result of these factors which are controlled to different degrees by genotype and the environment.

Selection of superior trees based on growth rate appears more useful because of its greater variability compared to density. Density is difficult to measure accurately in the field and must be done in the lab whereas the height/age data can be collected rapidly in the field.

The relationship between wood density and the various parameters shows two distinct characteristics: most of the correlation coefficients are negative (except for rings per cm where a positive

relation exists for most stands); and, very few of the r values are statistically significant (Table 3). The only significant relationships occur in the three stands over seventy years old. Even though the correlation coefficient was significantly different from zero, the degree of association with rate of growth was less than 20% in the oldest stand. These results are consistent with those reported by several authors which show a slight or negative relationship between density and growth rate in conifers; in jack pine (Hegyi 1969), white spruce (Chang and Kennedy 1967), in Douglas fir and Loblolly pine (Kellogg 1982, Bendsten 1978, Matziris and Zobel 1973).

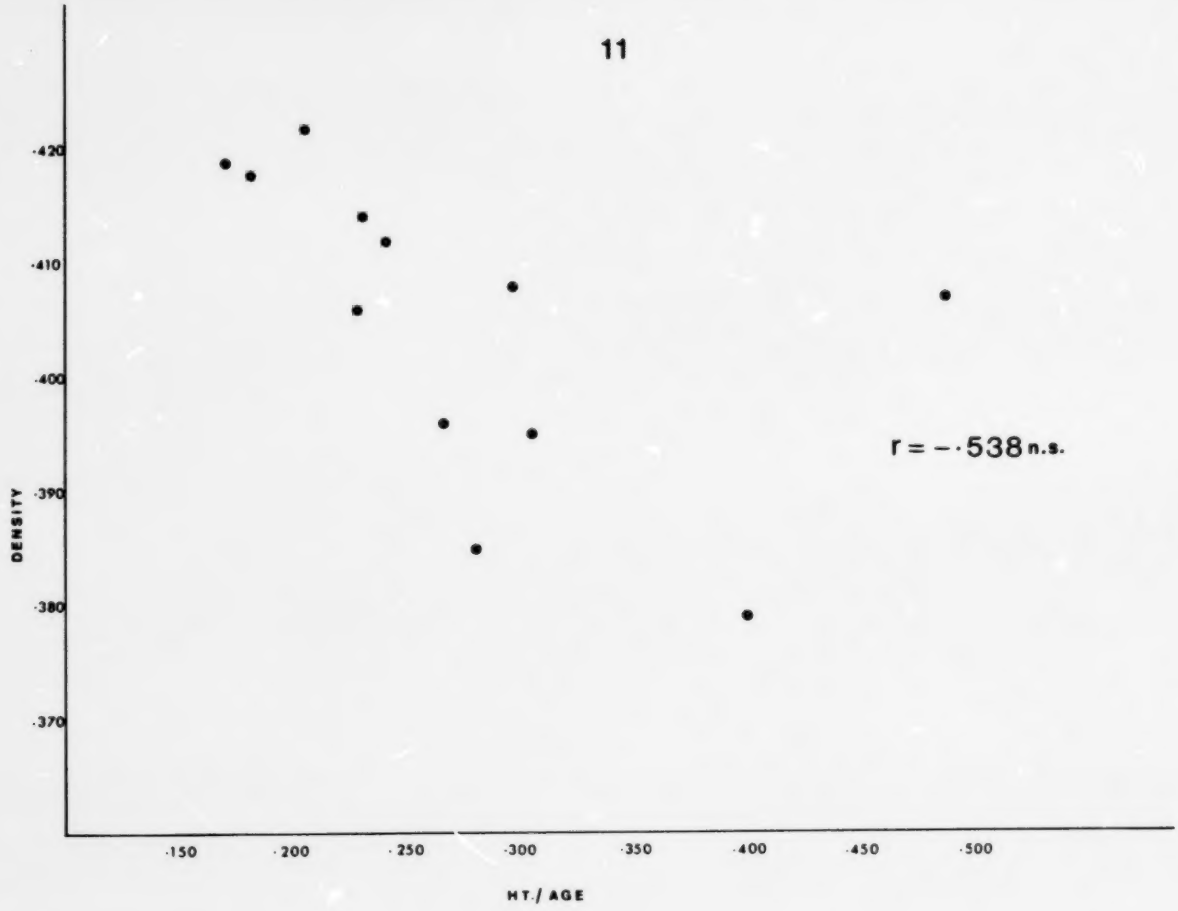
Table 3. Correlation between density and other parameters.

Stand	Stand age	Correlation Coefficients (r)				
		Age	Height	Diameter	Height/ age	Rings/cm
South Brook (1)	94.3	-.18	-.27*[1]	.46**	-.45**	.38**
Baie Verte	85.2	.10	-.16	-.19	-.21*	.24
Gambo Pond (1)	71.2	-.20	-.16	-.35*	.01	.20
Gambo Pond (2)	62.0	.18	.01	-.15	-.14	.20
Millertown Jct.	58.0	-.01	-.03	-.002	-.02	-.01
Deer Lake	57.3	.23	.05	-.19	-.18	.30
South Brook (2)	55.3	.35	.30	.06	.02	.11
Glenwood	52.9	-.19	-.02	-.15	.13	.07
Grand Falls	43.5	.003	-.12	.26	-.17	.27
North Pond (1)	26.1	-.03	-.11	-.06	-.01	-.01
Cormack	20.2	-.07	.06	-.02	-.10	.16
North Pond (2)	8.9	.07	-.05	-.07	-.09	.01

[1] r values followed by one asterisk are statistically significant at the 0.95 level of probability, two asterisks at 0.99 level.

The trends within stands indicate a weak negative relationship between growth rate and density. Although this is not strongly indicated in Table 3, a high level of covariation is apparent between stands when density and growth rate (height/age and rings/cm) are plotted against each other (Figure 2). The r value for density and height/age is not significant because of the small sample size. The relationship, however, is that of a decrease in density with an increase in growth rate. This is better reflected in the density on the rings/cm graph in which the relationship is statistically significant (Fig. 2). The overall stand to stand effects have a relationship which contrasts with the relationship within the individual stands.

The density and growth rate data for each of the 12 stands are shown in Figures 3-5. It is readily apparent that there is a weak relationship between growth rate and density. Based on the r values and from the data portrayed in the graphs it would appear that the selection of fast-growing trees as plus trees would sample from the normal range of density. Hence there would be no change (or improvement) in density in the new generation developed from the selected plus trees. There would be an equal likelihood of high or low density trees in a range of the fast-growing progeny. Thus the primary objective should be possible, that is to breed for fast-growing trees without sacrificing density. If density were sacrificed then much of the advantages of breeding for growth would be lost. As Spurr and Hsiung (1954) point out, "a fast growing tree will produce a higher volume of high density wood in later life than a slow-growing tree".



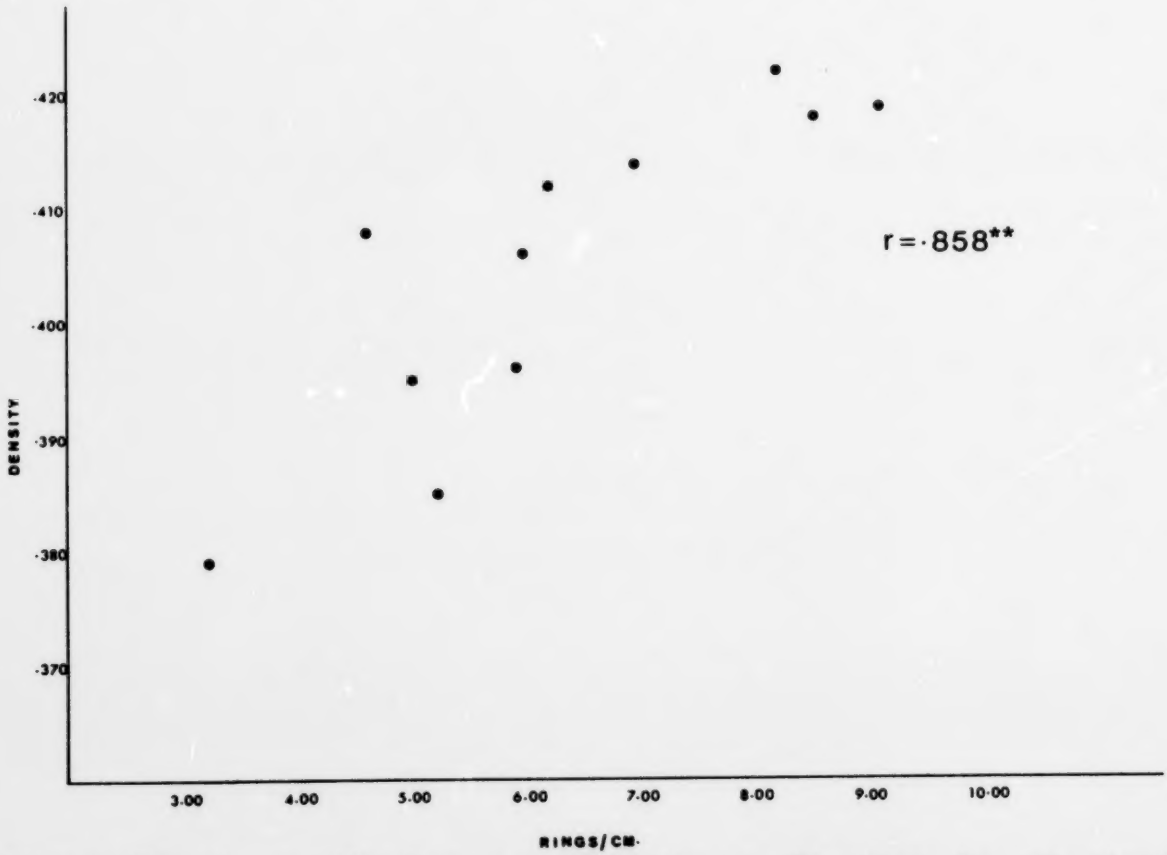
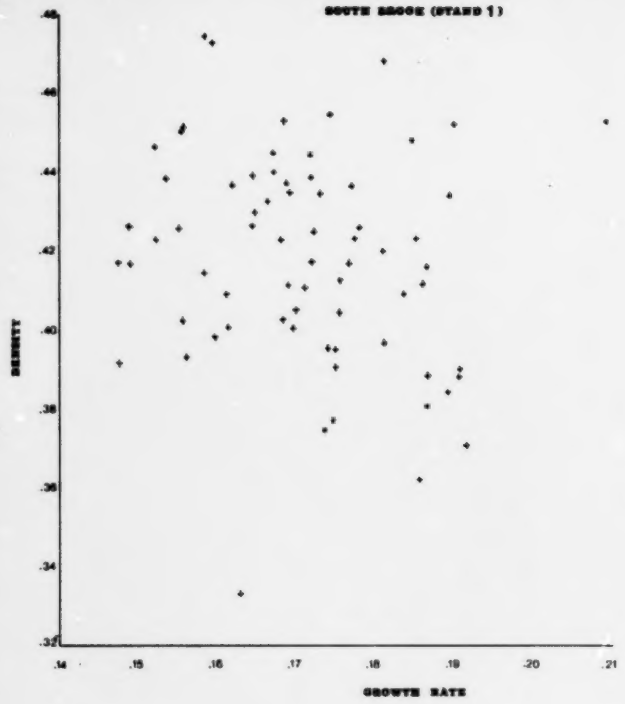
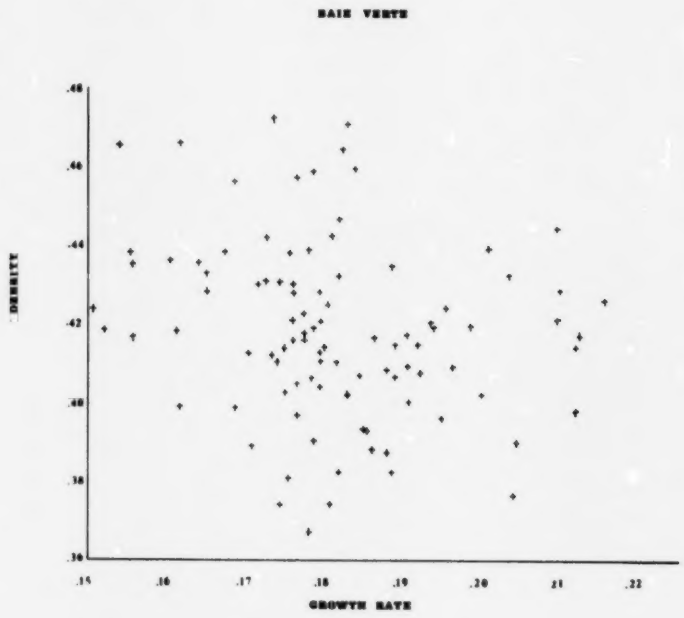
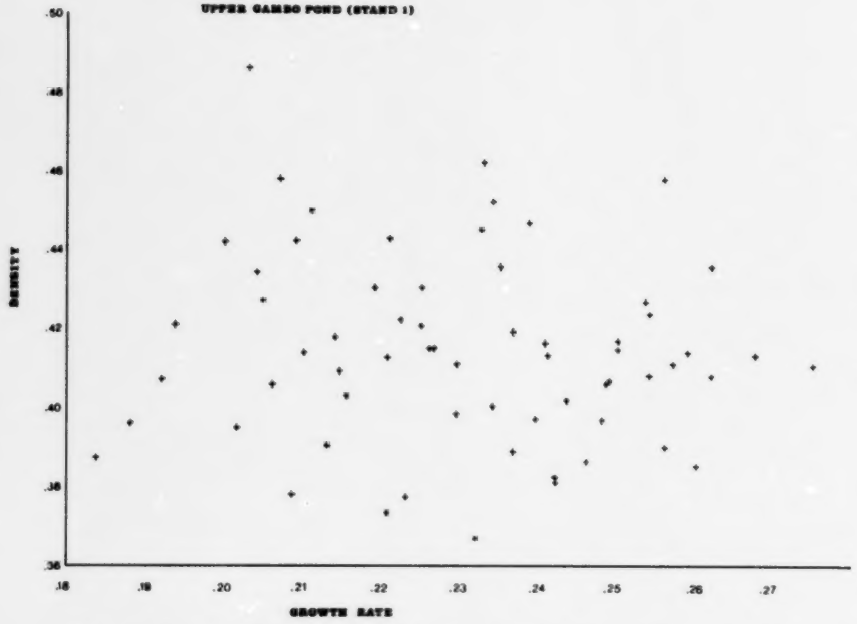


Figure 2. Density vs Ht./ Age and Density vs Rings/cm. for all stands.







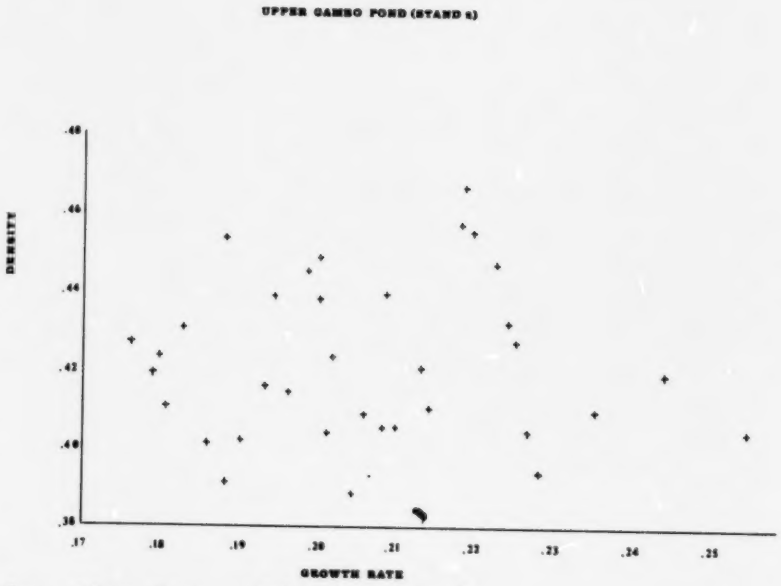
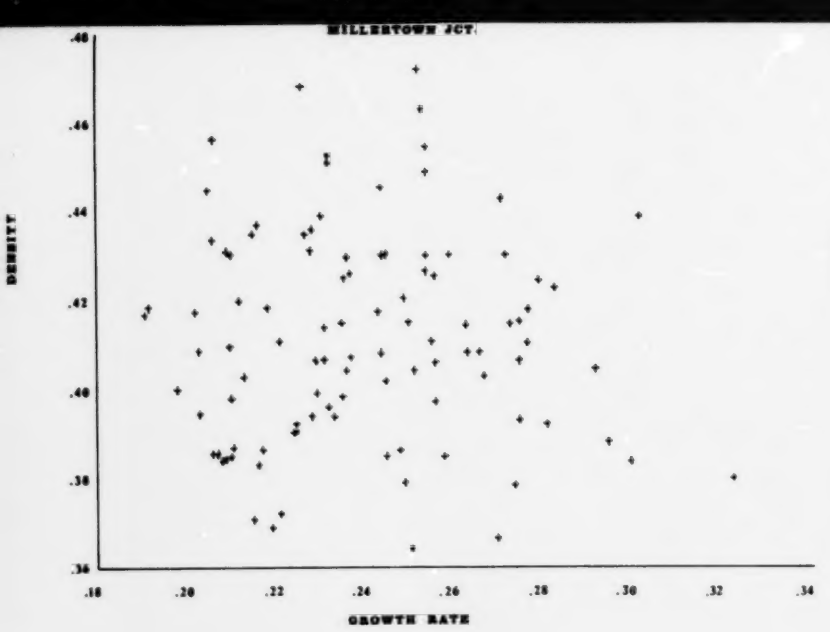
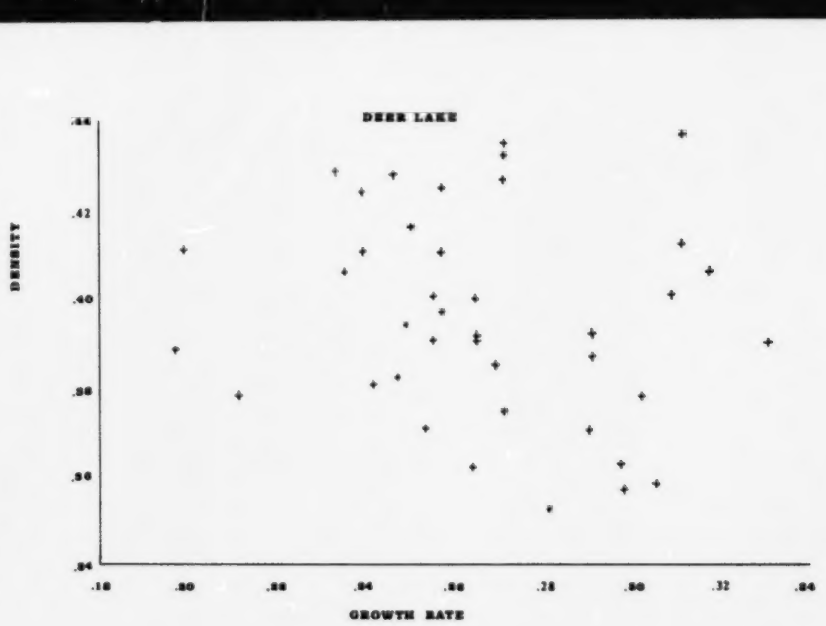
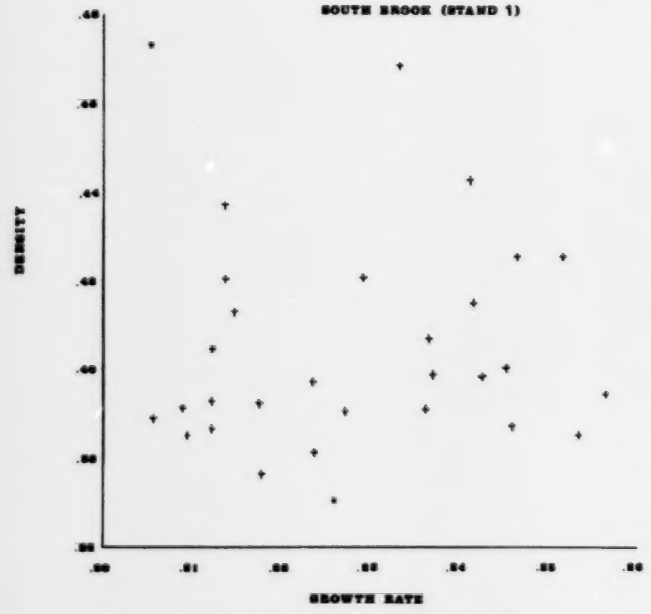


Figure 3. Density/Growth rate relationships for the four oldest stands.







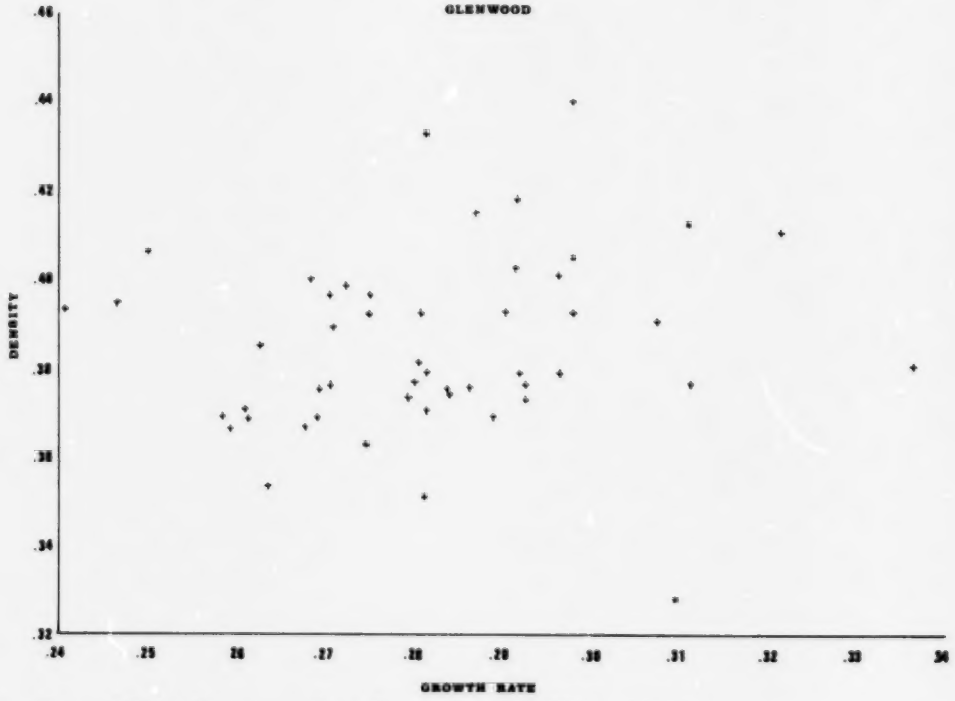


Figure 4. Density/Growth rate relationships for the four stands of middle age.

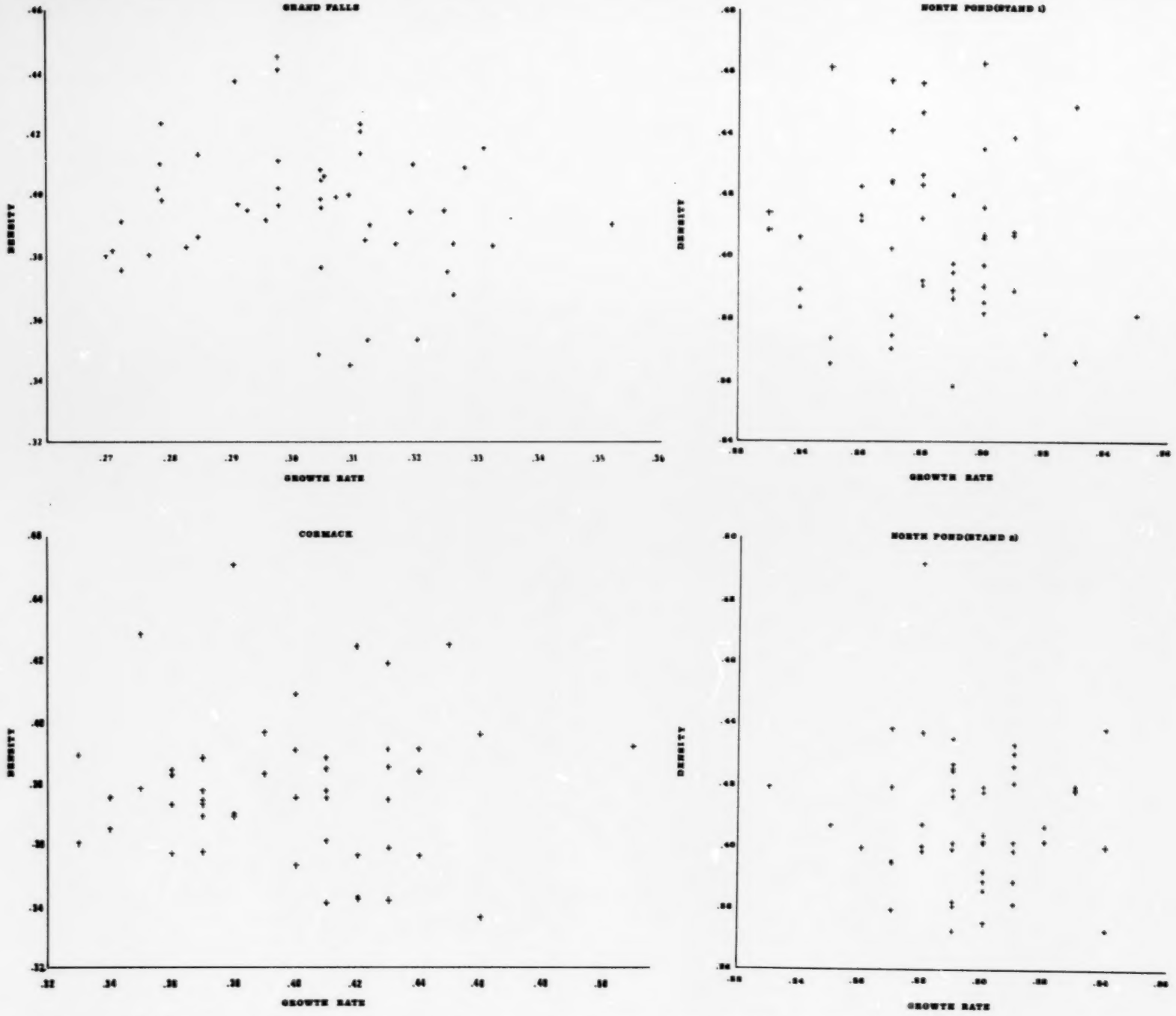


Figure 5. Density/Growth rate relationships for the four youngest stands.

EFFECTS OF SELECTING FASTEST GROWING OR HIGH DENSITY TREES

As a test of the selection method, the fastest growing tree in each stand was selected and the percentage increase above the stand average was calculated (Table 4). Differences of 15 to 30 percent in

Table 4. Percentage change from stand average when the best tree in each stand is selected for high growth rate or high density.

	Percentage change from stand average when selection is based on			
	Fastest Growth		Highest Density	
Stand	Growth change	Density change	Growth change	Density change
South Brook (1)	+22.4	+8.4	- 7.5	+13.4
Baie Verte	+16.9	-0.2	+ 0.7	+12.6
Gambo Pond (1)	+23.2	-8.5	-12.0	+17.3
Gambo Pond (2)	+23.6	-4.3	+ 6.0	+10.5
Millertown Jct.	+34.8	-7.7	+ 5.0	+14.6
Deer Lake	+24.0	-4.8	+16.6	+10.4
South Brook (2)	+12.5	-2.7	-10.0	+16.8
Glenwood	+14.1	+6.4	+ 5.6	+14.3
Grand Falls	+16.0	-1.2	- 2.0	+12.7
North Pond (1)	+16.4	-8.6	- 6.1	+20.5
Cormack	+28.1	+3.5	- 3.6	+19.1
North Pond (2)	+56.8	-8.0	+ 3.6	+13.7
Average change	+24.1	-2.3	- 0.3	+14.7

growth rate (height/age) were common and the highest potential increase was in the youngest stand at North Pond, the stand with the greatest variability (Table 2). It is probable that the variability is related to stand age and that much of this will disappear as the crowns close and competition begins. Selections based on a high rate of growth did not improve density. However, in seven of the twelve stands, selecting the fastest growing tree resulted in a loss of 2 percent or more in density. This level of 2 percent is great enough to have significant economic impacts on pulp yield (Kellogg 1982). In two of the stands, the loss in density was less than 2 percent; in the remaining three stands, there was a gain in wood density. Selections on the basis of growth rate are more practicable than on the basis of wood density, but from the data it is reasonable to assume that some of the gain in growth is likely to be offset by a reduction in density. The change in density is random but tends to be negative, resulting in a net economic loss. It appears that an improvement in method is necessary.

Selections based on wood density are more difficult because of the necessity of extracting increment cores and then assessing them in the laboratory. In Table 4, the effects of selecting plus trees on the basis of wood density indicates a gain over the stand average of 10 to 20 percent. This increase is considerably less than the potential percentage increase in volume possible when selecting on the basis of

growth rate. There are also low levels of within stand variation as shown in Table 2. However, when selecting on the basis of density, there is no overall net loss in growth rate and the difference in growth rate is negative for half the stands. The data indicate a more random distribution than was the case when selections were based on growth rate. In the stand at Deer Lake, the gain in growth rate is even higher than that for density, as the same tree is in the five best in each category. This occurred for one tree in each of the stands at South Brook (1) and Glenwood. This tree is the type which is most desirable, one which is good for both factors, rapid growth rate and high density.

Since average rate of height growth and wood density were independent genetic characteristics there was a risk of choosing trees with low wood density when the decision was based only on height growth. However, average wood density was not likely to be reduced when the number of trees chosen was large. Because height growth and wood density are independently determined, an opportunity exists to select for both traits and realize an improvement that approaches the sum of each increase.

It has been reported that for the southeastern hard pines selection for such individuals is economically sound and that half the difference between selected trees and the stand mean is recoverable in an improvement program based on selecting fast-growing individuals of high density (Zobel 1971). A two-stage procedure for selecting trees is recommended for black spruce. First, the fastest growing individuals in

the stand would be identified and then from within this group the tree of highest density would be selected as candidate plus tree.

Since the determination of density is slow and costly, a rapid field method is necessary. One method utilizes a spring driven pin which penetrates the tree to varying depths depending upon wood density. The method has proven useful in plantations of white spruce in Alberta (Micko et al. 1982). A machine was acquired by the Newfoundland Forest Research Centre in 1983 and a program of testing its efficacy in stands of black spruce and other conifers has begun. If the method proves to be useful, then it can be incorporated into a selection program and trees of both high growth rate and high density can be identified as plus trees. In this way, the tree improvement program can ensure that trees selected for breeding will not only be fast growing but that wood quality will also be permanently improved.

SUMMARY AND CONCLUSIONS

Selections of candidate plus trees in Newfoundland are based on rapid growth rates and do not consider wood density, a factor which is of moderate heritability and of high economic value. This study was begun to determine if growth rate and density were related, how selection methods affected growth rate and density in selected trees and if these methods needed modification.

Twelve stands ranging in age from 10 to 95 years were selected in central Newfoundland and stand parameters of height, age, diameter and wood density were measured. Relationships between growth rate and density were examined using correlation coefficients. The data indicated higher levels of variability in growth rate than in density and that the two were weakly indirectly related. Based on these statistics and on a trial selection of the tree with the fastest growth or highest density in a stand, it was apparent that selection of just one parameter was inadequate. Selection based only on rapid growth rate was quick but it reduced density slightly; selection based on density only, was time consuming but hardly affected growth rate. In order to capture both rapid growth rate and increased density, a method is suggested to first select a group of fast growing trees and then screen out trees of low density. This method ensures that subsequent generations will possess more rapid growth rates than current ones and that economically valuable increases in wood density will be obtained.

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